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Passive Badge Assessment for Long-term, Low-level Air Monitoring on Submarines: VOC Badge Validation

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14. ABSTRACT

Passive badge monitors for benzene, toluene, and xylene detection (cumulatively) were tested for analyte-specific air analysis onboard U.S. Navy (USN) nuclear submarines. Long-term sampling efficiency was evaluated for a 28-day period by comparing the response of the passive badge to an active tube sampling method. The badges and tubes were exposed to benzene, toluene, and xylene vapors at concentrations ranging from 0.33 to 1.98 ppm, resulting in time-weighted-average exposures ranging from 47-283 ppb. High- and low-level concentrations were tested to examine the response range of the badge. The badges continued to accumulate the analyte for 28 days, with no change in sampling rate over time. Badge results appeared to be stable and consistent, but were different than results observed from tubes. Accumulation of benzene onto badges was consistently higher than accumulation onto tubes (+24%), while the badge response to toluene and xylene was lower than that of the tubes (–40%, –49%). A correction factor may need to be applied to analytical results to obtain more accurate, quantitative data.

15. SUBJECT TERMS

Submarine atmospheric monitoring, SAHAP, Passive sampling, Passive badges, VOC, Benzene, Toluene, Xylene, Aromatic hydrocarbons, Air samples, NIOSH, OSHA, US Navy, OEL, Contamination levels

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Contents

Passive Badge Assessment for Long-term, Low-level Air Monitoring on Submarines: VOC Badge Validation

1.0 Introduction

The submarine is a unique working and living environment, as submariners are contained in this environment 24 hours a day for the duration of deployment. It is important to know and monitor the safety of the atmosphere to which they are exposed. Current methods of air monitoring onboard U.S. Navy (USN) nuclear submarines include the Central Atmosphere Monitoring System (CAMS) and active, colorimetric sampling tubes (Draeger). The CAMS provides continuous, real-time air analysis for only a few critical compounds. Draeger tubes provide real-time results for other species of interest, but sampling is not continuous. Additionally, the Draeger tube methods are labor intensive and have poor reproducibility because of the use of a manually operated hand pump, multiple interpretations of the manually read tube results, and less trained personnel. Implementing passive badges would greatly reduce sources of error, as they are professionally analyzed and require very little human manipulation. They may supplement or even replace certain sampling procedures while providing continuous air sampling, thereby relieving the sailors to perform other important duties onboard the submarine. Additionally, numerous analytes can be tested at the same time using one or multiple badges.

For use on submarines, passive badges should provide continuous air monitoring for up to 28 consecutive days. Before the badges can be used in this application, they must be validated for long-term use, as they are currently only validated commercially for a normal 8-hour working day. To assess their long-term responses, for exposures up to 28 days, the badges were compared to commonly-used active sampling tubes. The badges and tubes were simultaneously tested using exposure chambers that were designed to provide a homogenous test vapor to all sampling devices (*1*).

Sources of volatile organic compounds (VOC) include diesel fuels and off-gassed byproducts of solvent-based paints. Some VOCs, such as benzene, are known human carcinogens while exposure to other species may result in a range of symptoms including nausea, headaches, respiratory irritation, and systemic damage. This validation study focuses on the three most common aromatic VOCs: benzene, toluene, and xylene, often referred to as BTX. The OSHA time-weighted average (TWA) occupational exposure limits (OEL) for BTX are 1 ppm, 200 ppm and 100 ppm, respectively. However, because of the unique environment onboard submarines, the USN 90-day OEL for BTX was set at 0.1 ppm, 20 ppm, and 50 ppm, respectively. Passive badge monitoring for VOCs was evaluated for long-term exposures at levels similar to what has been observed aboard a USN nuclear submarine (*2*).

2.0 Experimental

Manuscript approved October 16, 2006.

2.1 Test Chambers

The test chambers were designed for the purpose of delivering a reproducible, homogenous test vapor, while simultaneously accommodating six passive badges and five active tubes. The clear Plexiglas® chambers are comprised of multiple sections: introduction chamber, mixing baffles, badge plate, tube ports, and a fan, as shown in Figure 1. The chamber's body is tubular, chosen over a traditional rectangular shape to reduce "dead" air space within corners of the chamber. The body is 10.8 cm in diameter (ID) and 30.5 cm long. A Plexiglas® plate within the chamber was designed to hold six badges, each being exposed to a uniform airstream at a specified face velocity, as shown in Figure 2. The sampling rate of the VOC badge, as specified by the manufacturer, was 3.85 mL/min for benzene, 3.8 mL/min for toluene, and 3.7 mL/min for xylene. To maintain this sampling rate, a minimal linear face velocity of $\geq$17 cm/sec, or 13 L/min, was sustained (*3*). The badge plate directed a total volume of 30 L/min of test vapor through the six 1.2 cm × 2 cm openings, one in front of each of the six badges, providing the appropriate face velocity. The fan at the back of the chamber pulled the test vapor through the chamber at approximately 29 L/min. A slight overpressure in the chamber prevented room air from leaking into the system. Two Plexiglas® mixing baffles at the front of the chamber aided in mixing the vapor stream.

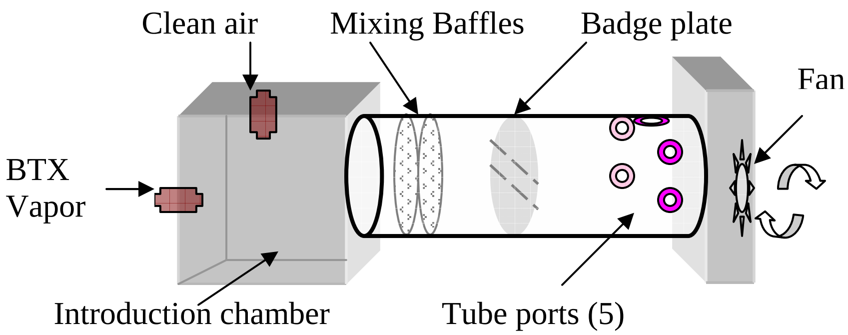

Figure 1. Diagram of a validation chamber.

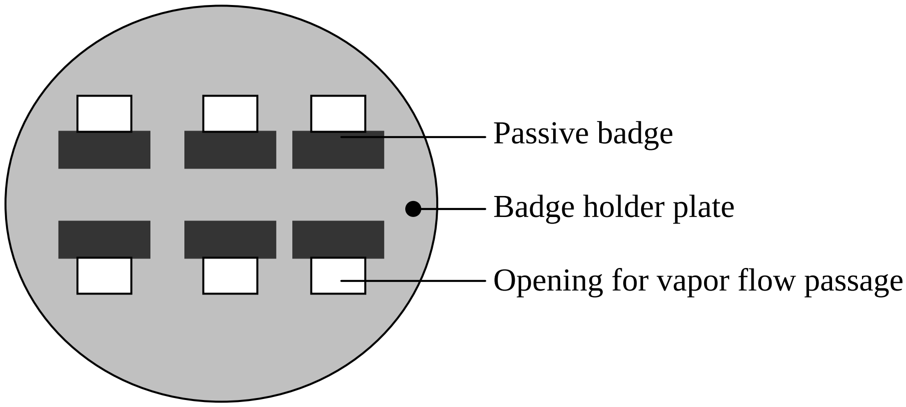

Figure 2. The badge plate, with 6-badge capacity.

2.2 Vapor Generation

Four test chambers and one control chamber were used for this study. Two of the test chambers tested a "low level" concentration of BTX and two of the chambers tested a "high level" concentration of BTX. The "high level" concentration was twice that of the "low level" concentration. BTX gas mixtures were generated using certified gas cylinders and syringe pump methods.

<u>Benzene and Toluene</u>

Benzene and toluene (BT) mixtures were supplied by certified gas cylinders (200 ppm benzene in air and 400 ppm toluene in air, Matheson Tri-gas, Montgomeryville, PA). Specific volumes of the mixtures were distributed among the four test chambers using Sierra mass flow controllers. Distribution of the BT mixtures was achieved with the use of adjustable, 4-port, manifolds, which split the BT flows among the four test chambers. Twice as much volume of the mixtures (100 mL/min benzene, 70 mL/min toluene) was delivered to the "high-level" chambers than was delivered to the "low-level" chambers (50 mL/min benzene, 35 mL/min toluene). Each chamber diluted the BT mixture into 30 L/min of clean, humidified air using Sierra mass flow controllers. Clean, humidified air was obtained by passing compressed house-air through dual-tower molecular sieves, removing moisture and CO_2, then through pressurized distilled water tanks for controlled rehumidification. Clean, humidified air, only, was delivered to the control chamber at all times. The flow rates of all controlled airstreams were measured using a Dry-Cal flow meter.

<u>Xylene</u>

Xylene vapor was generated using a syringe pump method. Neat xylene (Aldrich cat.# 247642) was pumped directly into the clean, humidified airstream where the compound was instantly vaporized before entering the chamber. The system, at the point of infusion, was heated to approximately 65ºC using electric heat tape to facilitate vaporization of the compound. The xylene was delivered at a rate of 0.3 µL/minute for all chambers.

The analyte exposures were conducted using the "pulse" method. Instead of exposing the samples to the analyte vapor continuously, the exposures were delivered four times per week. The concentrations of the pulsed BTX vapor were 0.33 ppm, 0.465 ppm and 0.99 ppm, respectively, for the low-level chambers and 0.66 ppm, 0.93 ppm, and 1.98 ppm, respectively, for the high-level chambers. Each pulsed exposure lasted approximately 360 minutes, after which time the gas cylinders were closed off manually and syringe pumps were automatically shut off. The syringe pumps were set to deliver a total volume of 108 µL per pulse for the high-level chambers and 54 µL per pulse for the low-level chambers. The cumulative, TWA exposure per week was equivalent to a continuous exposure of BTX at 47 ppb, 66 ppb, and 141 ppb for low-level exposure and 94 ppb, 133 ppb, and 283 ppb for high-level exposure. Equation 1 shows the calculation for determining the benzene concentration to be delivered per pulse for testing at 100% of

the Navy OEL. While the OELs for BTX on USN nuclear submarines are set at 0.1, 20, and 50 ppm, respectively, observed levels of BTX on a nuclear submarine were in the range of 2-23 ppb. Our study intended to expose badges at a level that was both realistic to actual levels of BTX as well as competent for monitoring levels approaching the OELs. Clean air was passed through the chambers continuously when the analyte was not being delivered. Running the pulse method was advantageous in monitoring system mechanics to ensure that all of the equipment was functioning properly. It may also be a more realistic demonstration of how the badge might respond to an instantaneous exposure to a hazardous compound.

Eq. 1

$$\frac{0.1\text{ ppm Benzene}}{\text{minute}} \times \frac{60\text{ minutes}}{\text{hour}} \times \frac{24\text{ hours}}{\text{day}} \times \frac{28\text{ days}}{\text{validation}} = \frac{4032\text{ Total ppm}}{\text{validation period}}$$

$$\frac{4032\text{ Total ppm Benzene}}{4\text{ weeks}} \times \frac{\text{week}}{4\text{ days}} \times \frac{\text{day}}{360\text{ minutes}} = \frac{0.7\text{ ppm pulsed}}{\text{minute}}$$

2.3 Sampling Methods

The analyte was collected onto passive badges (Assay Technology, Inc. #541) equipped with a coconut charcoal disk for VOC capture. The same chemistry was used by the active sampling tubes (SKC 226-16). The active tube samples were collected using a sample pump (SKC Airchek 224-PCXR7) to pull approximately 50 mL/min of vapor across each tube's substrate. Results obtained from all samples were compared against a standard curve covering the range of 0.4-230 µg, corresponding to the total analyte accumulated per sampler over time.

2.4 Experimental Procedure

The badges were inserted into the badge plate with the badge face facing the opening above it. The active sampling tubes were connected to adjustable, low-flow, four-tube manifolds (SKC 224-26-04). As a result, only four tubes were used per chamber, as opposed to the possible five. Each chamber's manifold allowed a single pump to sample for the four tubes attached. The pumps were set to collect 200 mL/min, to be distributed among the four sampling tubes, providing a nominal sampling rate of 50 mL/min per tube. Due to slight differences in the tubes as a result of manufacturing processes, the pressure drop across the tubes varied, resulting in small variations of flow though the tubes. Therefore, the flow rate of each tube was measured independently using an in-line Sierra mass flow meter before being inserted into the chamber and again before its removal. The average flow rate, per tube, was used when analyzing the final data results. The sampling rate of the badges was expected to remain constant.

The experiment ran for 4 weeks (28 days). Chambers "1" and "2" tested the high level, and Chambers "3" and "4" tested the low level. To monitor the progress of the experiment, a scheduled number of badges were systematically removed per week. These badges were analyzed to guarantee that the system was functioning properly and to assess the behavior of the badges over time. Active tubes were removed on a per-pulse basis. Each series of tubes monitored a single vapor pulse and the clean air period

following the pulse. The data was catalogued each week and used to compile a final data analysis at the end of the 28-day testing period. The badge removal schedule is illustrated in Figure 3. Each week three badges were removed from a low-level testing chamber and three badges were removed from a high-level testing chamber. Badges the

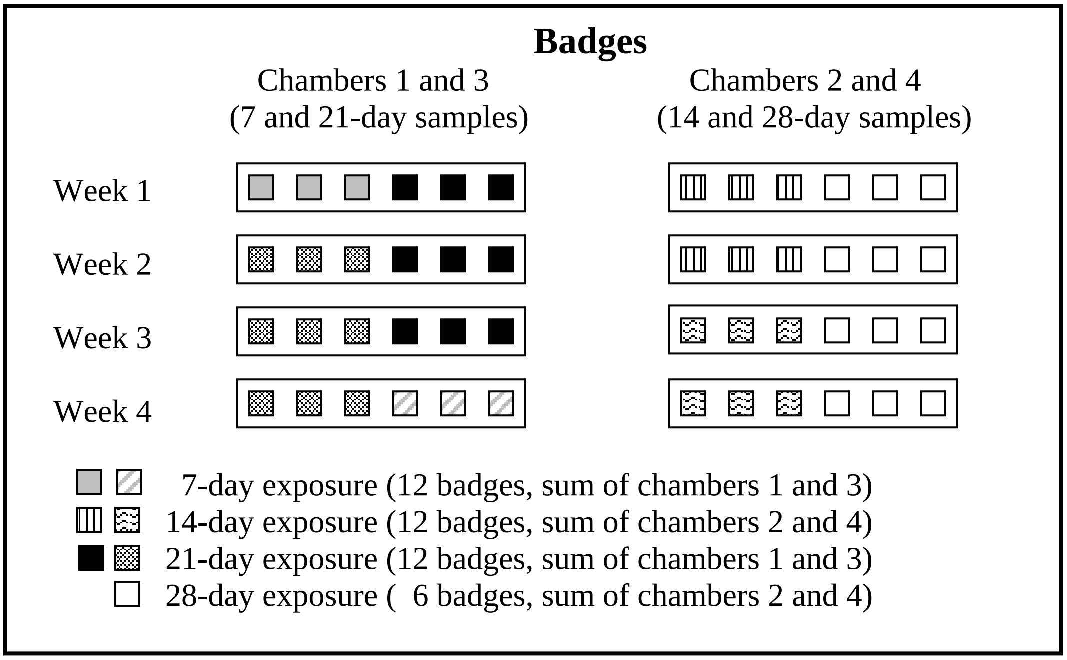

Figure 3. Schedule of badge removal/replacement.

first week were removed from chambers 1 and 3. The next week, badges were removed from chambers 2 and 4. This pattern was repeated for the duration of the validation. New badges were inserted in the chambers in place of the removed samples. Clean air was moving through the chambers as the change-outs occurred. At the end of the 28 days all of the remaining tubes and badges were removed from the chambers. Collectively, the badge data were representative of the first 7, 14, 21, and 28 days and for the last 7, 14, and 21 days. Tube data were representative of a single pulse exposure and were added together to formulate data for periods of 7, 14, 21, and 28-days.

2.5 Analysis

Each week, following removal from the test chamber, the tubes and badges were extracted for BTX analysis. Analysis was similar to NIOSH 1501 analytical method (*4*). The faces of the badges were removed to acquire the charcoal sample disc. The disc was transferred to a clean sample vial filled with 2 mL of carbon disulfide solvent (low-benzene, Aldrich cat.# 342270). The active sample tubes were scored then broken open to empty the contents into a clean sample vial filled with 2 mL of carbon disulfide solvent. The tube and badge samples were sonicated for 30-60 minutes, centrifuged to settle large particles, then small aliquots of sample were transferred to autosampler vials to be analyzed by gas chromatography (GC) (Agilent 6890). Specifications of the GC included: an Rtx-5 30 m, 0.25 id, 0.25 µm column, with auto-sampler injection and

flame ionization detection (FID) detection. The instrument conditions included injector and detector temperatures at 250°C and a temperature program as follows: 50°C (hold 2 min) to 95°C @15°C/min, to 150°C @30°C/min. The method runtime was 6.83 minutes with the retention times of benzene at 2.1 minutes, toluene at 2.9 minutes, and the 3 peak series for xylene at 4.0, 4.1, and 4.4 minutes. Sample data obtained from the GC were compared against the calibration curve. The curve was generated by spiking charcoal substrate with increasing amounts of benzene, toluene, and xylene solutions, then desorbing the samples in 2 mL of carbon disulfide.

A Draeger Chip Measurement System (CMS) analyzer was used to periodically verify the concentration of the BTX vapor in the test chambers.

3.0 Results and Discussion

Data were gathered and compiled on a daily/weekly basis by removing a scheduled number of tubes and badges from each chamber. The raw data are given in the Appendix. Calculations were based on measurements of the gas analyte, airstreams, and sampling rates. All sample values, tubes and badges, were calculated to reflect the concentration within the chamber (ppm), respective to each sample. Equation 2 demonstrates the determination of the concentration of benzene vapor within the test chamber, per sample. With all data presented in the same manner, direct comparisons could be made. Data from the control "clean" chamber showed no BTX contamination, indicating that there were no interferences causing false-positive results.

Eq. 2

$$\text{Total µg collected on sampler} \times \frac{}{\text{Tube / badge sampling rate, LPM}} \times \frac{}{\text{exposure period, minutes}} \times \frac{24.46\ \text{L}}{\text{mole Air}} \times \frac{\text{mole Benzene}}{78.11\ \text{g}} \times \frac{1\ \text{g}}{10^6\ \text{µg}} \times \frac{10^6}{} = \text{Benzene ppm}$$

The results indicate that the badges continued to collect the analytes for the entire 28-day sampling period. There did not appear to be a change in sampling rate over time or a limit of capacity. Results observed for tubes and badges, independently, were relatively consistent as indicated by acceptable relative standard deviation (RSD) values, <10% average, Table 1. However, the increased RSD levels, when comparing badges to tubes, verify that the badge results were different than the tube results, Table 2. Accumulation of benzene onto badges was consistently higher than accumulation onto tubes, while the badge response to toluene and xylene was lower than that of the tubes, Table 3. On average, the badge results were 24% greater for benzene, 40% lower for toluene, and 49% lower for xylene when compared to tube results.

Table 1. Relative standard deviation (RSD) values (%) observed for tubes and badges. Values <10% are considered stable and reproducible.

Tubes	%RSD range	Average
Benzene	0.4 - 22.8	5.0
Toluene	1.0 - 28.4	4.2
Xylene	0.9 - 29.8	7.4

Badges	%RSD range	Average
Benzene	0.9 - 22.3	7.6
Toluene	0.5 - 18.4	6.0
Xylene	2.3 - 21.0	8.5

Table 2. Relative standard deviation values (%) observed when comparing tubes and badges. Values <10% are considered stable and reproducible.

Badge, Tube comparison of same exposure period	%RSD range	Average
Benzene	4.5 - 26.2	14.7
Toluene	23.8 - 52.6	36.2
Xylene	23.2 - 52.6	46.7

Table 3. Percent recoveries of BTX (averaged), when compared to expected values.

Tubes	High level %Rec	Low level %Rec
Benzene	99	91
Toluene	106	100
Xylene	40	81

Badges	High level %Rec	Low level %Rec
Benzene	120	115
Toluene	62	58
Xylene	21	39

Although the badges did not provide the same level of response as the tubes, the badges did have similar behavioral patterns as the tubes, Appendix III-VI. Data obtained for measurements of benzene were more stable and consistent and showed similar results from badge and tube sampling. The toluene and xylene data were consistent among a single sampling method, but were variable when comparing the two sampling methods. This difference may be an indication of competitive analyte interferences. While all three BTX compounds were able to be sampled by a single badge, each compound had an independent sampling rate. This may have created a level of competition for mobility of each analyte to pass through the badge to adsorb onto the charcoal substrate. In this case benzene, with a higher sampling rate, would more likely have a greater rate of recovery, as observed in our study. If this is the case, then the sampling rates of the toluene and xylene were effectively changed, resulting in a difference of expected analyte accumulation. Upon further investigation, a correction factor may be applied to obtain more accurate information.

In addition, the syringe pumps being used for xylene vapor generation were observed working improperly at times. This would have resulted in lower recovery rates due to lack of xylene vapor generation. Unfortunately, the precise amount of xylene vapor being generated could not be verified independently of the sampling media. However, this still does not explain the variation observed between tubes and badges (Table 3). This was especially true for Chamber 1 (high level), where the most syringe pump problems were observed.

4.0 Conclusions

The results provided by the four sampling chambers were compared to establish response patterns of the passive badges, relative to active tubes, for benzene, toluene, and xylene over a 28-day exposure period. Badge results appeared to be stable and consistent, but

were different than results observed from tubes. The badges continued to accumulate the BTX for 28 days, with recovery of benzene greater than that onto tubes, and recoveries of toluene and xylene lower than that onto tubes. The badges were not limited by capacity of the sampling substrate and there did not appear to be a change in sampling rate over time. BTX gas mixtures were generated using certified gas cylinders and syringe pump methods. Using two different methods to generate the solvent vapors could account for some of the differences noted in the badge response.

5.0 References

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Appendix I – Raw data for active sampling tubes. Data are representative of a 50 mL/min sampling rate.

Table 1. Benzene - Chamber 1.

BENZENE--Chamber 1

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	37.83	379	18.95	0.63	36.61	379	18.95	0.61
Pulse 2	38.19	373	18.65	0.64	39.09	373	18.65	0.66
Pulse 3	37.93	361	18.05	0.66	36.51	361	18.05	0.63
Pulse 4	38.58	360	18.00	0.67	38.28	360	18.00	0.67
Pulse 5	37.83	360	18.00	0.66	33.50	360	18.00	0.58
Pulse 6	31.12	373	18.65	0.52	32.98	373	18.65	0.55
Pulse 7	36.05	361	18.05	0.63	35.81	361	18.05	0.62
Pulse 8	36.39	364	18.20	0.63	34.16	364	18.20	0.59
Pulse 9	33.53	359	17.95	0.58	31.21	359	17.95	0.54
Pulse 10	33.70	360	18.00	0.59	35.87	360	18.00	0.62
Pulse 11	39.18	379	18.95	0.65	38.90	379	18.95	0.64
Pulse 12	43.51	363	18.15	0.75	40.67	363	18.15	0.70
Pulse 13	43.66	366	18.30	0.75	40.45	366	18.30	0.69
Pulse 14	44.03	376	18.80	0.73	43.70	376	18.80	0.73
Pulse 15	43.81	356	17.80	0.77	37.69	356	17.80	0.66
Pulse 16	47.24	371	18.55	0.80	42.51	371	18.55	0.72

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	36.65	379	18.95	0.61	36.46	379	18.95	0.60
Pulse 2	38.57	373	18.65	0.65	39.64	373	18.65	0.67
Pulse 3	36.67	361	18.05	0.64	35.34	361	18.05	0.61
Pulse 4	38.22	360	18.00	0.66	38.17	360	18.00	0.66
Pulse 5	33.09	360	18.00	0.58	33.57	360	18.00	0.58
Pulse 6	32.04	373	18.65	0.54	37.49	373	18.65	0.63
Pulse 7	37.07	361	18.05	0.64	38.04	361	18.05	0.66
Pulse 8	34.97	364	18.20	0.60	34.05	364	18.20	0.59
Pulse 9	34.41	359	17.95	0.60	38.83	359	17.95	0.68
Pulse 10	36.33	360	18.00	0.63	32.92	360	18.00	0.57
Pulse 11	39.24	379	18.95	0.65	39.22	379	18.95	0.65
Pulse 12	40.72	363	18.15	0.70	43.06	363	18.15	0.74
Pulse 13	45.37	366	18.30	0.78	44.63	366	18.30	0.76
Pulse 14	40.70	376	18.80	0.68	42.58	376	18.80	0.71
Pulse 15	41.35	356	17.80	0.73	40.56	356	17.80	0.71
Pulse 16	39.90	371	18.55	0.67	42.53	371	18.55	0.72

Table 2. Toluene - Chamber 1.

TOLUENE--Chamber 1

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	61.23	379	18.95	0.86	63.28	379	18.95	0.89
Pulse 2	64.86	373	18.65	0.92	65.69	373	18.65	0.94
Pulse 3	65.97	361	18.05	0.97	63.50	361	18.05	0.93
Pulse 4	66.99	360	18.00	0.99	63.92	360	18.00	0.94
Pulse 5	63.10	360	18.00	0.93	62.76	360	18.00	0.93
Pulse 6	61.03	373	18.65	0.87	62.35	373	18.65	0.89
Pulse 7	34.14	203	10.15	0.89	34.03	203	10.15	0.89
Pulse 8			Toluene tank empty. New tanks have not arrived yet.					
Pulse 9								
Pulse 10								
Pulse 11	61.65	379	18.95	0.86	59.56	379	18.95	0.83
Pulse 12	62.37	363	18.15	0.91	61.85	363	18.15	0.90
Pulse 13	60.45	366	18.30	0.88	56.66	366	18.30	0.82
Pulse 14	67.16	376	18.80	0.95	64.17	376	18.80	0.91
Pulse 15	64.45	356	17.80	0.96	60.11	356	17.80	0.90
Pulse 16	58.00	371	18.55	0.83	60.46	371	18.55	0.87

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	60.70	379	18.95	0.85	56.72	379	18.95	0.79
Pulse 2	66.69	373	18.65	0.95	67.53	373	18.65	0.96
Pulse 3	65.05	361	18.05	0.96	60.94	361	18.05	0.90
Pulse 4	64.77	360	18.00	0.96	65.47	360	18.00	0.97
Pulse 5	61.21	360	18.00	0.90	57.43	360	18.00	0.85
Pulse 6	60.25	373	18.65	0.86	67.70	373	18.65	0.96
Pulse 7	35.80	203	10.15	0.94	35.40	203	10.15	0.93
Pulse 8			Toluene tank empty. New tanks have not arrived yet.					
Pulse 9								
Pulse 10								
Pulse 11	59.26	379	18.95	0.83	59.72	379	18.95	0.84
Pulse 12	62.63	363	18.15	0.92	63.97	363	18.15	0.94
Pulse 13	66.50	366	18.30	0.96	58.21	366	18.30	0.84
Pulse 14	58.43	376	18.80	0.83	63.23	376	18.80	0.89
Pulse 15	61.53	356	17.80	0.92	60.34	356	17.80	0.90
Pulse 16	60.54	371	18.55	0.87	61.81	371	18.55	0.88

Table 3. Xylene - Chamber 1.

XYLENE--Chamber 1

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	76.43	360	18.00	0.98	82.25	360	18.00	1.05
Pulse 2	72.93	360	18.00	0.93	73.92	360	18.00	0.95
Pulse 3	33.01	360	18.00	0.42	30.99	360	18.00	0.40
Pulse 4	114.61	360	18.00	1.47	105.50	360	18.00	1.35
Pulse 5	7.69	360	18.00	0.10	7.24	360	18.00	0.09
Pulse 6	27.93	360	18.00	0.36	29.42	360	18.00	0.38
Pulse 7	93.18	360	18.00	1.19	91.71	360	18.00	1.17
Pulse 8	7.04	360	18.00	0.09	5.12	360	18.00	0.07
Pulse 9	18.30	360	18.00	0.23	14.51	360	18.00	0.19
Pulse 10	97.19	360	18.00	1.24	99.88	360	18.00	1.28
Pulse 11	37.78	360	18.00	0.48	38.58	360	18.00	0.49
Pulse 12	12.57	360	18.00	0.16	11.61	360	18.00	0.15
Pulse 13	48.30	360	18.00	0.62	49.23	360	18.00	0.63
Pulse 14	34.36	360	18.00	0.44	35.22	360	18.00	0.45
Pulse 15	107.66	360	18.00	1.38	104.16	360	18.00	1.33
Pulse 16	17.78	360	18.00	0.23	18.74	360	18.00	0.24

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	74.75	360	18.00	0.96	71.44	360	18.00	0.91
Pulse 2	76.03	360	18.00	0.97	76.97	360	18.00	0.99
Pulse 3	31.59	360	18.00	0.40	29.75	360	18.00	0.38
Pulse 4	110.46	360	18.00	1.41	109.46	360	18.00	1.40
Pulse 5	3.99	360	18.00	0.05	6.11	360	18.00	0.08
Pulse 6	27.03	360	18.00	0.35	29.69	360	18.00	0.38
Pulse 7	97.02	360	18.00	1.24	93.44	360	18.00	1.20
Pulse 8	3.55	360	18.00	0.05	4.72	360	18.00	0.06
Pulse 9	16.40	360	18.00	0.21	22.74	360	18.00	0.29
Pulse 10	97.81	360	18.00	1.25	97.92	360	18.00	1.25
Pulse 11	35.09	360	18.00	0.45	37.47	360	18.00	0.48
Pulse 12	13.65	360	18.00	0.17	11.00	360	18.00	0.14
Pulse 13	60.04	360	18.00	0.77	44.43	360	18.00	0.57
Pulse 14	30.00	360	18.00	0.38	30.79	360	18.00	0.39
Pulse 15	102.92	360	18.00	1.32	101.76	360	18.00	1.30
Pulse 16	20.11	360	18.00	0.26	17.95	360	18.00	0.23

Pulse events shown in bold type (5,8,9,12, and 16) are those during which a syringe pump malfunction was observed.

Table 4. Benzene - Chamber 2.

BENZENE--Chamber 2

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	36.028	379	18.95	0.60	38.066	379	18.95	0.63
Pulse 2	37.924	373	18.65	0.64	36.619	373	18.65	0.61
Pulse 3	39.769	361	18.05	0.69	39.093	361	18.05	0.68
Pulse 4	38.819	360	18.00	0.68	38.608	360	18.00	0.67
Pulse 5	36.862	360	18.00	0.64	37.166	360	18.00	0.65
Pulse 6	40.771	373	18.65	0.68	28.634	373	18.65	0.48
Pulse 7	34.814	361	18.05	0.60	34.498	361	18.05	0.60
Pulse 8	31.792	364	18.20	0.55	32.208	364	18.20	0.55
Pulse 9	34.447	359	17.95	0.60	34.063	359	17.95	0.59
Pulse 10	37.867	360	18.00	0.66	36.905	360	18.00	0.64
Pulse 11	37.772	379	18.95	0.62	38.593	379	18.95	0.64
Pulse 12	38.669	363	18.15	0.67	38.192	363	18.15	0.66
Pulse 13	44.423	366	18.30	0.76	42.359	366	18.30	0.72
Pulse 14	44.783	376	18.80	0.75	44.407	376	18.80	0.74
Pulse 15	44.291	356	17.80	0.78	38.230	356	17.80	0.67
Pulse 16	43.706	371	18.55	0.74	38.412	371	18.55	0.65

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	32.952	379	18.95	0.54	36.896	379	18.95	0.61
Pulse 2	39.099	373	18.65	0.66	35.790	373	18.65	0.60
Pulse 3	36.968	361	18.05	0.64	39.350	361	18.05	0.68
Pulse 4	36.302	360	18.00	0.63	36.260	360	18.00	0.63
Pulse 5	38.236	360	18.00	0.67	39.566	360	18.00	0.69
Pulse 6	37.237	373	18.65	0.63	35.693	373	18.65	0.60
Pulse 7	35.703	361	18.05	0.62	35.901	361	18.05	0.62
Pulse 8	32.273	364	18.20	0.56	35.309	364	18.20	0.61
Pulse 9	33.377	359	17.95	0.58	27.757	359	17.95	0.48
Pulse 10	36.273	360	18.00	0.63	35.653	360	18.00	0.62
Pulse 11	38.690	379	18.95	0.64	38.508	379	18.95	0.64
Pulse 12	43.633	363	18.15	0.75	42.599	363	18.15	0.73
Pulse 13	41.657	366	18.30	0.71	42.591	366	18.30	0.73
Pulse 14	44.283	376	18.80	0.74	42.350	376	18.80	0.71
Pulse 15	40.282	356	17.80	0.71	40.522	356	17.80	0.71
Pulse 16	39.008	371	18.55	0.66	40.583	371	18.55	0.69

Table 5. Toluene - Chamber 2.

TOLUENE--Chamber 2

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	66.381	379	18.95	0.93	61.426	379	18.95	0.86
Pulse 2	64.749	373	18.65	0.92	62.918	373	18.65	0.90
Pulse 3	70.012	361	18.05	1.03	67.539	361	18.05	0.99
Pulse 4	66.774	360	18.00	0.98	67.130	360	18.00	0.99
Pulse 5	63.763	360	18.00	0.94	65.227	360	18.00	0.96
Pulse 6	69.835	373	18.65	0.99	61.445	373	18.65	0.87
Pulse 7	32.753	203	10.15	0.86	32.342	203	10.15	0.85
Pulse 8	Toluene tank empty. New tanks have not arrived yet.							
Pulse 9								
Pulse 10								
Pulse 11	58.235	379	18.95	0.82	60.383	379	18.95	0.85
Pulse 12	63.850	363	18.15	0.93	61.749	363	18.15	0.90
Pulse 13	64.988	366	18.30	0.94	62.375	366	18.30	0.90
Pulse 14	67.135	376	18.80	0.95	65.426	376	18.80	0.92
Pulse 15	63.535	356	17.80	0.95	60.509	356	17.80	0.90
Pulse 16	63.772	371	18.55	0.91	61.272	371	18.55	0.88

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	57.815	379	18.95	0.81	63.697	379	18.95	0.89
Pulse 2	67.203	373	18.65	0.96	64.045	373	18.65	0.91
Pulse 3	60.442	361	18.05	0.89	64.689	361	18.05	0.95
Pulse 4	63.400	360	18.00	0.94	64.096	360	18.00	0.95
Pulse 5	61.836	360	18.00	0.91	66.547	360	18.00	0.98
Pulse 6	66.690	373	18.65	0.95	65.766	373	18.65	0.94
Pulse 7	33.807	203	10.15	0.88	33.733	203	10.15	0.88
Pulse 8	Toluene tank empty. New tanks have not arrived yet.							
Pulse 9								
Pulse 10								
Pulse 11	59.976	379	18.95	0.84	58.850	379	18.95	0.82
Pulse 12	61.855	363	18.15	0.90	64.740	363	18.15	0.95
Pulse 13	61.703	366	18.30	0.90	64.876	366	18.30	0.94
Pulse 14	64.892	376	18.80	0.92	59.624	376	18.80	0.84
Pulse 15	62.963	356	17.80	0.94	61.693	356	17.80	0.92
Pulse 16	61.318	371	18.55	0.88	61.482	371	18.55	0.88

Table 6. Xylene - Chamber 2.

XYLENE--Chamber 2

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	31.732	360	18.00	0.41	29.195	360	18.00	0.37
Pulse 2	30.891	360	18.00	0.40	30.152	360	18.00	0.39
Pulse 3	47.583	360	18.00	0.61	46.021	360	18.00	0.59
Pulse 4	55.555	360	18.00	0.71	57.025	360	18.00	0.73
Pulse 5	53.483	360	18.00	0.68	53.356	360	18.00	0.68
Pulse 6	69.629	360	18.00	0.89	60.512	360	18.00	0.77
Pulse 7	41.454	360	18.00	0.53	40.521	360	18.00	0.52
Pulse 8	42.595	360	18.00	0.55	43.342	360	18.00	0.55
Pulse 9	53.897	360	18.00	0.69	51.545	360	18.00	0.66
Pulse 10	60.616	360	18.00	0.78	58.160	360	18.00	0.74
Pulse 11	42.370	360	18.00	0.54	44.467	360	18.00	0.57
Pulse 12	70.947	360	18.00	0.91	63.830	360	18.00	0.82
Pulse 13	74.790	360	18.00	0.96	69.551	360	18.00	0.89
Pulse 14	78.312	360	18.00	1.00	80.640	360	18.00	1.03
Pulse 15	87.823	360	18.00	1.12	76.673	360	18.00	0.98
Pulse 16	53.740	360	18.00	0.69	48.343	360	18.00	0.62

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	28.649	360	18.00	0.37	32.196	360	18.00	0.41
Pulse 2	33.208	360	18.00	0.43	31.169	360	18.00	0.40
Pulse 3	40.223	360	18.00	0.51	44.432	360	18.00	0.57
Pulse 4	53.628	360	18.00	0.69	55.297	360	18.00	0.71
Pulse 5	54.619	360	18.00	0.70	58.884	360	18.00	0.75
Pulse 6	67.444	360	18.00	0.86	68.700	360	18.00	0.88
Pulse 7	45.940	360	18.00	0.59	42.892	360	18.00	0.55
Pulse 8	47.386	360	18.00	0.61	47.659	360	18.00	0.61
Pulse 9	51.815	360	18.00	0.66	32.358	360	18.00	0.41
Pulse 10	56.970	360	18.00	0.73	61.462	360	18.00	0.79
Pulse 11	44.542	360	18.00	0.57	45.269	360	18.00	0.58
Pulse 12	64.975	360	18.00	0.83	70.153	360	18.00	0.90
Pulse 13	70.779	360	18.00	0.91	76.750	360	18.00	0.98
Pulse 14	74.231	360	18.00	0.95	69.154	360	18.00	0.89
Pulse 15	95.431	360	18.00	1.22	91.178	360	18.00	1.17
Pulse 16	44.408	360	18.00	0.57	40.753	360	18.00	0.52

Table 7. Benzene - Chamber 3.

BENZENE--Chamber 3

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	15.391	379	18.95	0.25	15.996	379	18.95	0.26
Pulse 2	17.123	373	18.65	0.29	16.839	373	18.65	0.28
Pulse 3	16.436	361	18.05	0.29	16.737	361	18.05	0.29
Pulse 4	16.978	360	18.00	0.30	17.194	360	18.00	0.30
Pulse 5	15.583	360	18.00	0.27	17.307	360	18.00	0.30
Pulse 6	13.624	373	18.65	0.23	17.195	373	18.65	0.29
Pulse 7	16.085	361	18.05	0.28	16.845	361	18.05	0.29
Pulse 8	15.778	364	18.20	0.27	15.775	364	18.20	0.27
Pulse 9	14.896	359	17.95	0.26	15.106	359	17.95	0.26
Pulse 10	15.341	360	18.00	0.27	15.109	360	18.00	0.26
Pulse 11	15.104	379	18.95	0.25	17.779	379	18.95	0.29
Pulse 12	17.797	363	18.15	0.31	17.525	363	18.15	0.30
Pulse 13	17.130	366	18.30	0.29	18.726	366	18.30	0.32
Pulse 14	18.887	376	18.80	0.31	19.521	376	18.80	0.33
Pulse 15	17.747	356	17.80	0.31	17.306	356	17.80	0.30
Pulse 16	16.925	371	18.55	0.29	18.825	371	18.55	0.32

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	16.687	379	18.95	0.28	16.164	379	18.95	0.27
Pulse 2	17.491	373	18.65	0.29	17.505	373	18.65	0.29
Pulse 3	16.987	361	18.05	0.29	16.259	361	18.05	0.28
Pulse 4	15.773	360	18.00	0.27	15.866	360	18.00	0.28
Pulse 5	17.502	360	18.00	0.30	18.861	360	18.00	0.33
Pulse 6	16.019	373	18.65	0.27	16.538	373	18.65	0.28
Pulse 7	15.094	361	18.05	0.26	16.383	361	18.05	0.28
Pulse 8	15.309	364	18.20	0.26	15.858	364	18.20	0.27
Pulse 9	15.425	359	17.95	0.27	15.882	359	17.95	0.28
Pulse 10	15.773	360	18.00	0.27	16.909	360	18.00	0.29
Pulse 11	16.250	379	18.95	0.27	17.059	379	18.95	0.28
Pulse 12	17.889	363	18.15	0.31	18.260	363	18.15	0.32
Pulse 13	18.153	366	18.30	0.31	17.531	366	18.30	0.30
Pulse 14	18.315	376	18.80	0.31	18.603	376	18.80	0.31
Pulse 15	17.953	356	17.80	0.32	17.133	356	17.80	0.30
Pulse 16	18.438	371	18.55	0.31	18.399	371	18.55	0.31

Table 8. Toluene - Chamber 3.

TOLUENE--Chamber 3

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	26.279	379	18.95	0.37	24.505	379	18.95	0.34
Pulse 2	27.549	373	18.65	0.39	26.192	373	18.65	0.37
Pulse 3	26.475	361	18.05	0.39	28.117	361	18.05	0.41
Pulse 4	27.889	360	18.00	0.41	28.728	360	18.00	0.42
Pulse 5	25.631	360	18.00	0.38	27.131	360	18.00	0.40
Pulse 6	26.172	373	18.65	0.37	29.317	373	18.65	0.42
Pulse 7	14.671	203	10.15	0.38	15.279	203	10.15	0.40
Pulse 8			Toluene tank empty. New tanks have not arrived yet.					
Pulse 9								
Pulse 10								
Pulse 11	20.979	379	18.95	0.29	25.086	379	18.95	0.35
Pulse 12	24.283	363	18.15	0.36	24.899	363	18.15	0.36
Pulse 13	22.991	366	18.30	0.33	25.366	366	18.30	0.37
Pulse 14	25.701	376	18.80	0.36	26.709	376	18.80	0.38
Pulse 15	24.756	356	17.80	0.37	25.111	356	17.80	0.37
Pulse 16	25.283	371	18.55	0.36	25.552	371	18.55	0.37

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	27.716	379	18.95	0.39	25.390	379	18.95	0.36
Pulse 2	27.839	373	18.65	0.40	28.225	373	18.65	0.40
Pulse 3	28.090	361	18.05	0.41	28.235	361	18.05	0.42
Pulse 4	25.528	360	18.00	0.38	25.544	360	18.00	0.38
Pulse 5	27.726	360	18.00	0.41	27.592	360	18.00	0.41
Pulse 6	28.115	373	18.65	0.40	29.466	373	18.65	0.42
Pulse 7	14.092	203	10.15	0.37	15.576	203	10.15	0.41
Pulse 8			Toluene tank empty. New tanks have not arrived yet.					
Pulse 9								
Pulse 10								
Pulse 11	23.346	379	18.95	0.33	24.952	379	18.95	0.35
Pulse 12	22.753	363	18.15	0.33	25.758	363	18.15	0.38
Pulse 13	24.509	366	18.30	0.36	24.968	366	18.30	0.36
Pulse 14	24.842	376	18.80	0.35	26.311	376	18.80	0.37
Pulse 15	25.325	356	17.80	0.38	24.925	356	17.80	0.37
Pulse 16	25.707	371	18.55	0.37	24.685	371	18.55	0.35

Table 9. Xylene - Chamber 3.

XYLENE--Chamber 3

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	21.261	360	18.00	0.27	19.463	360	18.00	0.25
Pulse 2	28.054	360	18.00	0.36	26.112	360	18.00	0.33
Pulse 3	28.745	360	18.00	0.37	31.661	360	18.00	0.41
Pulse 4	53.588	360	18.00	0.69	56.910	360	18.00	0.73
Pulse 5	42.273	360	18.00	0.54	49.781	360	18.00	0.64
Pulse 6	44.811	360	18.00	0.57	50.517	360	18.00	0.65
Pulse 7	44.461	360	18.00	0.57	48.907	360	18.00	0.63
Pulse 8	23.963	360	18.00	0.31	26.505	360	18.00	0.34
Pulse 9	30.063	360	18.00	0.38	34.007	360	18.00	0.44
Pulse 10	36.720	360	18.00	0.47	35.304	360	18.00	0.45
Pulse 11	35.480	360	18.00	0.45	45.496	360	18.00	0.58
Pulse 12	53.976	360	18.00	0.69	53.789	360	18.00	0.69
Pulse 13	47.933	360	18.00	0.61	53.078	360	18.00	0.68
Pulse 14	43.547	360	18.00	0.56	52.827	360	18.00	0.68
Pulse 15	53.920	360	18.00	0.69	53.829	360	18.00	0.69
Pulse 16	53.111	360	18.00	0.68	49.653	360	18.00	0.64

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	23.264	360	18.00	0.30	21.051	360	18.00	0.27
Pulse 2	28.476	360	18.00	0.36	28.489	360	18.00	0.36
Pulse 3	30.572	360	18.00	0.39	31.627	360	18.00	0.40
Pulse 4	49.513	360	18.00	0.63	50.905	360	18.00	0.65
Pulse 5	52.315	360	18.00	0.67	52.446	360	18.00	0.67
Pulse 6	46.035	360	18.00	0.59	48.964	360	18.00	0.63
Pulse 7	43.663	360	18.00	0.56	45.689	360	18.00	0.58
Pulse 8	22.372	360	18.00	0.29	24.429	360	18.00	0.31
Pulse 9	33.833	360	18.00	0.43	35.914	360	18.00	0.46
Pulse 10	37.796	360	18.00	0.48	37.223	360	18.00	0.48
Pulse 11	40.504	360	18.00	0.52	39.726	360	18.00	0.51
Pulse 12	48.919	360	18.00	0.63	58.096	360	18.00	0.74
Pulse 13	51.502	360	18.00	0.66	54.647	360	18.00	0.70
Pulse 14	44.558	360	18.00	0.57	48.800	360	18.00	0.62
Pulse 15	55.004	360	18.00	0.70	48.029	360	18.00	0.61
Pulse 16	53.021	360	18.00	0.68	48.954	360	18.00	0.63

Table 10. Benzene - Chamber 4.

BENZENE--Chamber 4

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	15.574	379	18.95	0.26	17.144	379	18.95	0.28
Pulse 2	18.258	373	18.65	0.31	20.005	373	18.65	0.34
Pulse 3	17.513	361	18.05	0.30	16.559	361	18.05	0.29
Pulse 4	16.791	360	18.00	0.29	17.702	360	18.00	0.31
Pulse 5	16.833	360	18.00	0.29	20.531	360	18.00	0.36
Pulse 6	20.765	373	18.65	0.35	18.950	373	18.65	0.32
Pulse 7	15.893	361	18.05	0.28	16.866	361	18.05	0.29
Pulse 8	15.722	364	18.20	0.27	15.982	364	18.20	0.27
Pulse 9	17.214	359	17.95	0.30	15.617	359	17.95	0.27
Pulse 10	17.687	360	18.00	0.31	17.251	360	18.00	0.30
Pulse 11	18.765	379	18.95	0.31	18.489	379	18.95	0.31
Pulse 12	19.827	363	18.15	0.34	20.710	363	18.15	0.36
Pulse 13	19.611	366	18.30	0.34	21.414	366	18.30	0.37
Pulse 14	21.314	376	18.80	0.36	21.691	376	18.80	0.36
Pulse 15	17.935	356	17.80	0.32	21.439	356	17.80	0.38
Pulse 16	19.006	371	18.55	0.32	20.400	371	18.55	0.34

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	18.421	379	18.95	0.30	17.465	379	18.95	0.29
Pulse 2	18.455	373	18.65	0.31	20.810	373	18.65	0.35
Pulse 3	17.665	361	18.05	0.31	10.261	361	18.05	0.18
Pulse 4	14.445	360	18.00	0.25	16.446	360	18.00	0.29
Pulse 5	19.100	360	18.00	0.33	18.313	360	18.00	0.32
Pulse 6	18.759	373	18.65	0.31	18.095	373	18.65	0.30
Pulse 7	17.392	361	18.05	0.30	16.474	361	18.05	0.29
Pulse 8	16.009	364	18.20	0.28	12.178	364	18.20	0.21
Pulse 9	15.162	359	17.95	0.26	15.978	359	17.95	0.28
Pulse 10	15.035	360	18.00	0.26	17.215	360	18.00	0.30
Pulse 11	19.257	379	18.95	0.32	19.007	379	18.95	0.31
Pulse 12	20.790	363	18.15	0.36	20.568	363	18.15	0.35
Pulse 13	20.129	366	18.30	0.34	20.719	366	18.30	0.35
Pulse 14	20.480	376	18.80	0.34	19.209	376	18.80	0.32
Pulse 15	19.597	356	17.80	0.34	19.754	356	17.80	0.35
Pulse 16	20.793	371	18.55	0.35	19.080	371	18.55	0.32

Table 11. Toluene - Chamber 4.

TOLUENE--Chamber 4

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	26.914	379	18.95	0.38	28.562	379	18.95	0.40
Pulse 2	28.463	373	18.65	0.41	30.704	373	18.65	0.44
Pulse 3	29.495	361	18.05	0.43	28.275	361	18.05	0.42
Pulse 4	28.123	360	18.00	0.41	29.308	360	18.00	0.43
Pulse 5	26.502	360	18.00	0.39	31.114	360	18.00	0.46
Pulse 6	32.300	373	18.65	0.46	31.593	373	18.65	0.45
Pulse 7	15.580	203	10.15	0.41	15.075	203	10.15	0.39
Pulse 8			Toluene tank empty. New tanks have not arrived yet.					
Pulse 9								
Pulse 10								
Pulse 11	26.385	379	18.95	0.37	26.594	379	18.95	0.37
Pulse 12	28.867	363	18.15	0.42	29.333	363	18.15	0.43
Pulse 13	28.579	366	18.30	0.41	30.277	366	18.30	0.44
Pulse 14	29.965	376	18.80	0.42	30.110	376	18.80	0.43
Pulse 15	24.664	356	17.80	0.37	27.704	356	17.80	0.41
Pulse 16	26.377	371	18.55	0.38	28.302	371	18.55	0.41

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	30.818	379	18.95	0.43	28.440	379	18.95	0.40
Pulse 2	29.374	373	18.65	0.42	33.500	373	18.65	0.48
Pulse 3	28.639	361	18.05	0.42	14.524	361	18.05	0.21
Pulse 4	27.526	360	18.00	0.41	27.936	360	18.00	0.41
Pulse 5	29.716	360	18.00	0.44	30.465	360	18.00	0.45
Pulse 6	31.489	373	18.65	0.45	31.690	373	18.65	0.45
Pulse 7	15.116	203	10.15	0.40	15.202	203	10.15	0.40
Pulse 8			Toluene tank empty. New tanks have not arrived yet.					
Pulse 9								
Pulse 10								
Pulse 11	27.340	379	18.95	0.38	27.946	379	18.95	0.39
Pulse 12	29.224	363	18.15	0.43	29.803	363	18.15	0.44
Pulse 13	29.069	366	18.30	0.42	29.023	366	18.30	0.42
Pulse 14	29.490	376	18.80	0.42	27.731	376	18.80	0.39
Pulse 15	26.249	356	17.80	0.39	27.322	356	17.80	0.41
Pulse 16	29.035	371	18.55	0.42	26.877	371	18.55	0.38

Table 12. Xylene - Chamber 4.

XYLENE--Chamber 4

	Tube 1 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 2 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	34.754	360	18.00	0.44	36.279	360	18.00	0.46
Pulse 2	29.516	360	18.00	0.38	31.935	360	18.00	0.41
Pulse 3	63.752	360	18.00	0.82	61.600	360	18.00	0.79
Pulse 4	37.363	360	18.00	0.48	39.834	360	18.00	0.51
Pulse 5	56.698	360	18.00	0.73	69.674	360	18.00	0.89
Pulse 6	59.355	360	18.00	0.76	57.261	360	18.00	0.73
Pulse 7	47.098	360	18.00	0.60	46.575	360	18.00	0.60
Pulse 8	35.149	360	18.00	0.45	35.320	360	18.00	0.45
Pulse 9	52.157	360	18.00	0.67	48.475	360	18.00	0.62
Pulse 10	34.928	360	18.00	0.45	39.366	360	18.00	0.50
Pulse 11	45.350	360	18.00	0.58	45.157	360	18.00	0.58
Pulse 12	68.489	360	18.00	0.88	68.210	360	18.00	0.87
Pulse 13	62.349	360	18.00	0.80	69.853	360	18.00	0.89
Pulse 14	66.432	360	18.00	0.85	71.626	360	18.00	0.92
Pulse 15	46.171	360	18.00	0.59	56.776	360	18.00	0.73
Pulse 16	53.274	360	18.00	0.68	60.459	360	18.00	0.77

	Tube 3 total µg	pulse time	volume sampled, L	conc in chanber, ppm	Tube 4 total µg	pulse time	volume sampled, L	conc in chanber, ppm
Pulse 1	38.615	360	18.00	0.49	37.239	360	18.00	0.48
Pulse 2	30.762	360	18.00	0.39	35.928	360	18.00	0.46
Pulse 3	62.436	360	18.00	0.80	30.213	360	18.00	0.39
Pulse 4	35.693	360	18.00	0.46	37.541	360	18.00	0.48
Pulse 5	66.298	360	18.00	0.85	70.004	360	18.00	0.90
Pulse 6	59.418	360	18.00	0.76	61.060	360	18.00	0.78
Pulse 7	45.989	360	18.00	0.59	46.040	360	18.00	0.59
Pulse 8	34.177	360	18.00	0.44	25.068	360	18.00	0.32
Pulse 9	48.162	360	18.00	0.62	49.892	360	18.00	0.64
Pulse 10	28.832	360	18.00	0.37	33.217	360	18.00	0.43
Pulse 11	47.168	360	18.00	0.60	50.725	360	18.00	0.65
Pulse 12	69.339	360	18.00	0.89	69.498	360	18.00	0.89
Pulse 13	65.748	360	18.00	0.84	64.079	360	18.00	0.82
Pulse 14	68.330	360	18.00	0.87	66.983	360	18.00	0.86
Pulse 15	44.698	360	18.00	0.57	55.886	360	18.00	0.72
Pulse 16	61.643	360	18.00	0.79	55.440	360	18.00	0.71

Appendix II – Raw data for passive sampling badges.

Table 1. Benzene.

BENZENE

Chamber 1

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
7-a	13.07	1473	5.67	0.72
7-a	13.19	1473	5.67	0.73
7-a	15.31	1473	5.67	0.85
21-a	46.13	4392	16.91	0.85
21-a	47.26	4392	16.91	0.88
21-a	50.61	4392	16.91	0.94
21-b	46.61	4388	16.89	0.86
21-b	48.37	4388	16.89	0.90
21-b	43.48	4388	16.89	0.81
7-b	15.03	1469	5.66	0.83
7-b	14.96	1469	5.66	0.83
7-b	14.12	1469	5.66	0.78

Chamber 2

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
14-a	22.41	2931	11.28	0.62
14-a	24.00	2931	11.28	0.67
14-a	25.34	2931	11.28	0.70
28-a	53.91	5861	22.56	0.75
28-a	60.35	5861	22.56	0.84
28-a	51.87	5861	22.56	0.72
14-b	27.87	2930	11.28	0.77
14-b	28.15	2930	11.28	0.78
14-b	27.66	2930	11.28	0.77

Chamber 3

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
7-a	5.11	1473	5.67	0.28
7-a	8.06	1473	5.67	0.45
7-a	6.99	1473	5.67	0.39
21-a	21.55	4392	16.91	0.40
21-a	23.77	4392	16.91	0.44
21-a	20.80	4392	16.91	0.39
21-b	23.96	4388	16.89	0.44
21-b	19.05	4388	16.89	0.35
21-b	19.09	4388	16.89	0.35
7-b	6.76	1469	5.66	0.37
7-b	8.50	1469	5.66	0.47
7-b	8.04	1469	5.66	0.45

Chamber 4

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
14-a	11.89	2931	11.28	0.33
14-a	12.27	2931	11.28	0.34
14-a	11.72	2931	11.28	0.33
28-a	25.65	5861	22.56	0.36
28-a	27.55	5861	22.56	0.38
28-a	26.25	5861	22.56	0.36
14-b	11.62	2930	11.28	0.32
14-b	13.09	2930	11.28	0.36
14-b	14.81	2930	11.28	0.41

Samples designated with "-a" are original samples placed in chambers; "-b" are replacements for original samples that were removed for analysis.

Table 2. Toluene.

TOLUENE

Chamber 1

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
7-a	12.09	1473	5.60	0.57
7-a	12.47	1473	5.60	0.59
7-a	13.92	1473	5.60	0.66
21-a	27.57	3151	11.97	0.61
21-a	28.64	3151	11.97	0.63
21-a	30.50	3151	11.97	0.68
21-b	25.22	3147	11.96	0.56
21-b	29.30	3147	11.96	0.65
21-b	27.38	3147	11.96	0.61
7-b	11.92	1469	5.58	0.57
7-b	12.11	1469	5.58	0.58
7-b	11.21	1469	5.58	0.53

Chamber 2

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
14-a	17.22	2409	9.15	0.50
14-a	17.39	2409	9.15	0.50
14-a	17.27	2409	9.15	0.50
28-a	37.72	4620	17.56	0.57
28-a	43.64	4620	17.56	0.66
28-a	35.67	4620	17.56	0.54
14-b	17.26	2211	8.40	0.55
14-b	17.62	2211	8.40	0.56
14-b	16.70	2211	8.40	0.53

Chamber 3

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
7-a	5.82	1473	5.60	0.28
7-a	6.26	1473	5.60	0.30
7-a	5.90	1473	5.60	0.28
21-a	12.34	3151	11.97	0.27
21-a	13.88	3151	11.97	0.31
21-a	11.86	3151	11.97	0.26
21-b	14.99	3147	11.96	0.33
21-b	10.74	3147	11.96	0.24
21-b	11.41	3147	11.96	0.25
7-b	5.30	1469	5.58	0.25
7-b	5.79	1469	5.58	0.28
7-b	5.68	1469	5.58	0.27

Chamber 4

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
14-a	10.14	2409	9.15	0.29
14-a	10.51	2409	9.15	0.30
14-a	9.80	2409	9.15	0.28
28-a	16.95	4620	17.56	0.26
28-a	17.16	4620	17.56	0.26
28-a	16.59	4620	17.56	0.25
14-b	7.12	2211	8.40	0.22
14-b	8.01	2211	8.40	0.25
14-b	8.30	2211	8.40	0.26

Samples designated with "-a" are original samples placed in chambers; "-b" are replacements for original samples that were removed for analysis.

Table 3. Xylene.

XYLENE

Chamber 1

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
7-a	11.79	1440	5.33	0.51
7-a	12.64	1440	5.33	0.55
7-a	13.27	1440	5.33	0.57
21-a	28.99	4320	15.98	0.42
21-a	31.41	4320	15.98	0.45
21-a	33.98	4320	15.98	0.49
21-b	23.63	4320	15.98	0.34
21-b	28.84	4320	15.98	0.42
21-b	26.39	4320	15.98	0.38
7-b	7.86	1440	5.33	0.34
7-b	6.64	1440	5.33	0.29
7-b	5.63	1440	5.33	0.24

Chamber 2

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
14-a	11.52	2880	10.66	0.25
14-a	11.46	2880	10.66	0.25
14-a	12.69	2880	10.66	0.27
28-a	42.26	5760	21.31	0.46
28-a	53.87	5760	21.31	0.58
28-a	43.20	5760	21.31	0.47
14-b	21.11	2880	10.66	0.46
14-b	22.90	2880	10.66	0.50
14-b	21.74	2880	10.66	0.47

Chamber 3

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
7-a	5.85	1440	5.33	0.25
7-a	6.40	1440	5.33	0.28
7-a	5.98	1440	5.33	0.26
21-a	27.63	4320	15.98	0.40
21-a	31.39	4320	15.98	0.45
21-a	27.19	4320	15.98	0.39
21-b	43.02	4320	15.98	0.62
21-b	29.78	4320	15.98	0.43
21-b	31.12	4320	15.98	0.45
7-b	8.82	1440	5.33	0.38
7-b	8.74	1440	5.33	0.38
7-b	9.56	1440	5.33	0.41

Chamber 4

days of exposure	total µg	exposure time	volume sampled, L	conc in chanber, ppm
14-a	13.20	2880	10.66	0.29
14-a	14.54	2880	10.66	0.31
14-a	13.20	2880	10.66	0.29
28-a	40.58	5760	21.31	0.44
28-a	39.62	5760	21.31	0.43
28-a	38.73	5760	21.31	0.42
14-b	16.78	2880	10.66	0.36
14-b	20.44	2880	10.66	0.44
14-b	20.53	2880	10.66	0.44

Samples designated with "-a" are original samples placed in chambers; "-b" are replacements for original samples that were removed for analysis.

Appendix III - Tube, Badge comparison at high level exposure. Data are representative of a 50 mL/min sampling rate.

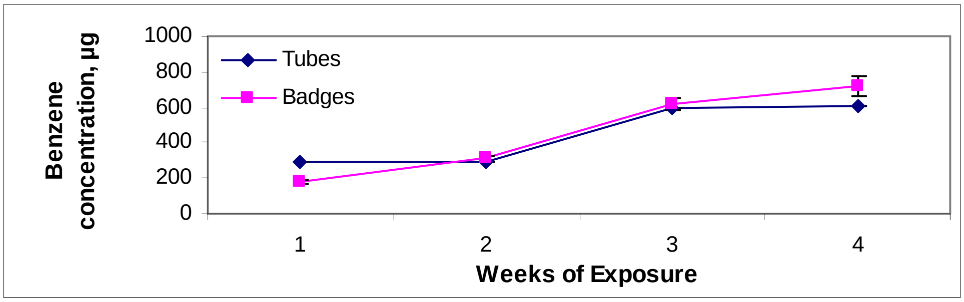

Figure 1. Benzene - 28 days (4 weeks).

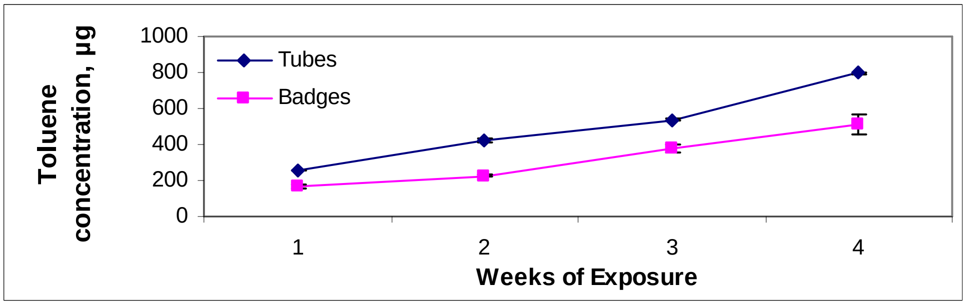

Figure 2. Toluene - 28 days (4 weeks).

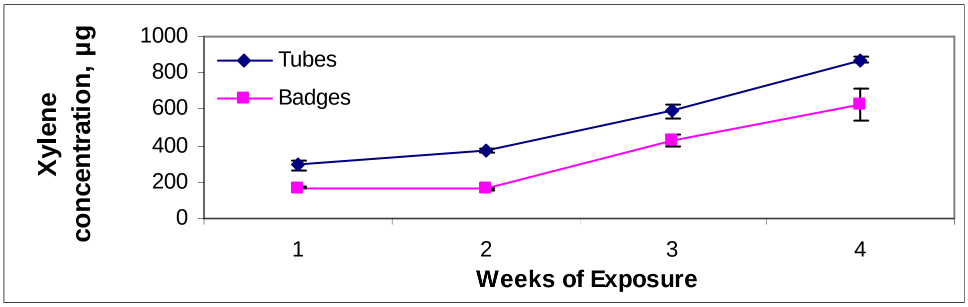

Figure 3. Xylene - 28 days (4 weeks).

Appendix IV - Tube, Badge comparison at low level exposure. Data are representative of a 50 mL/min sampling rate.

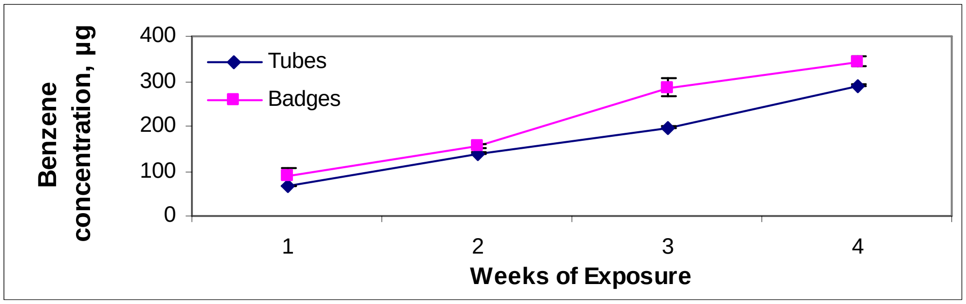

Figure 1. Benzene - 28 days (4 weeks).

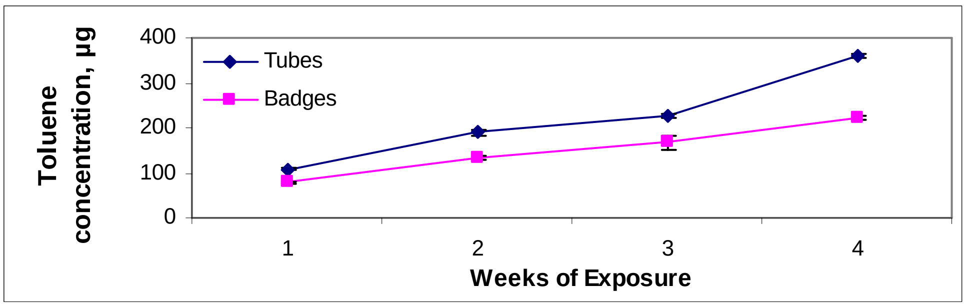

Figure 2. Toluene - 28 days (4 weeks).

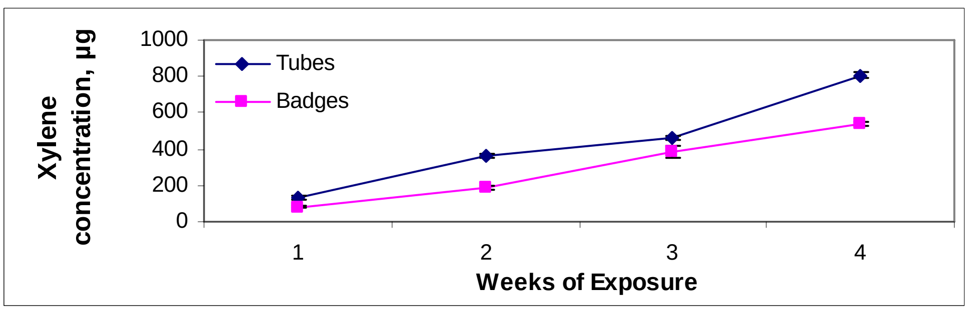

Figure 3. Xylene - 28 days (4 weeks).

Appendix V - Tube, Badge comparison (replacement badges) high level.
Data are representative of a 50 mL/min sampling rate.

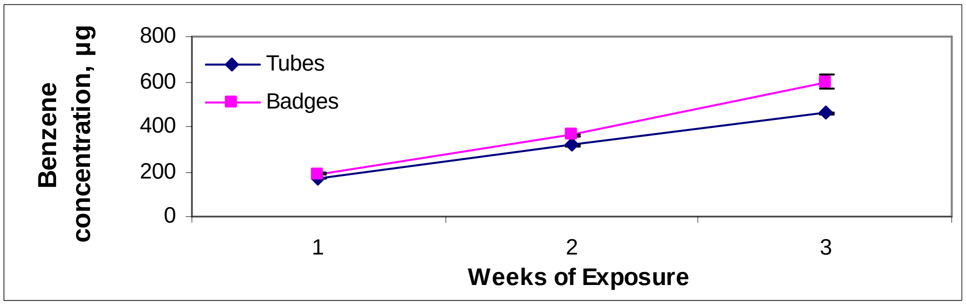

Figure 1. Benzene - 21 days (3 weeks).

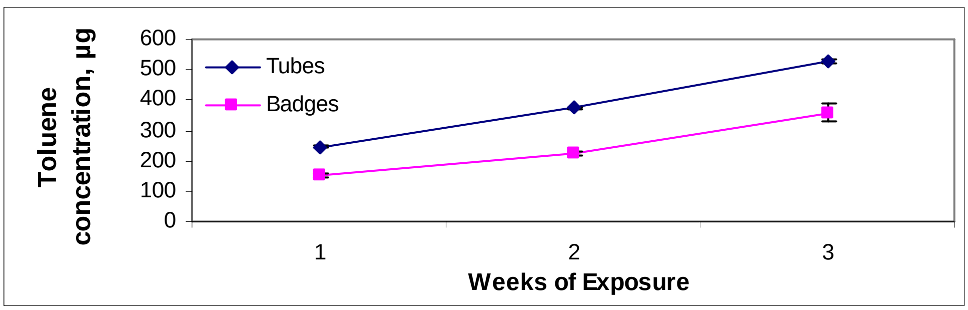

Figure 2. Toluene - 21 days (3 weeks).

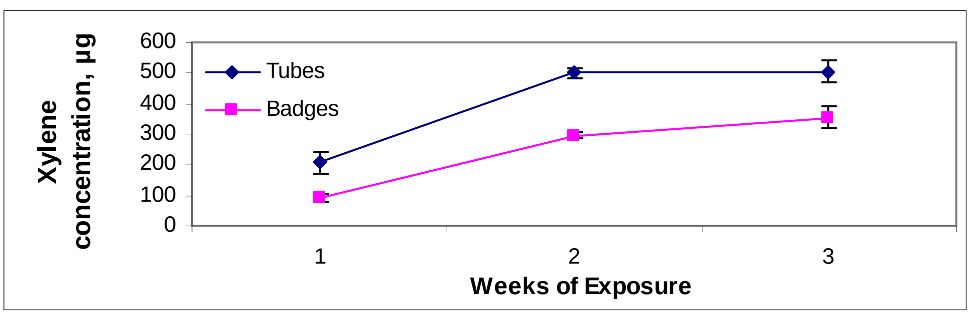

Figure 3. Xylene - 21 days (3 weeks).

Appendix VI - Tube, Badge comparison (replacement badges) low level.

Data are representative of a 50 mL/min sampling rate.

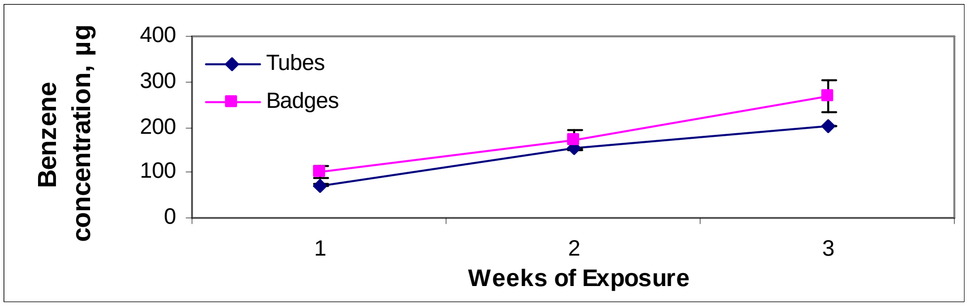

Figure 1. Benzene - 21 days (3 weeks).

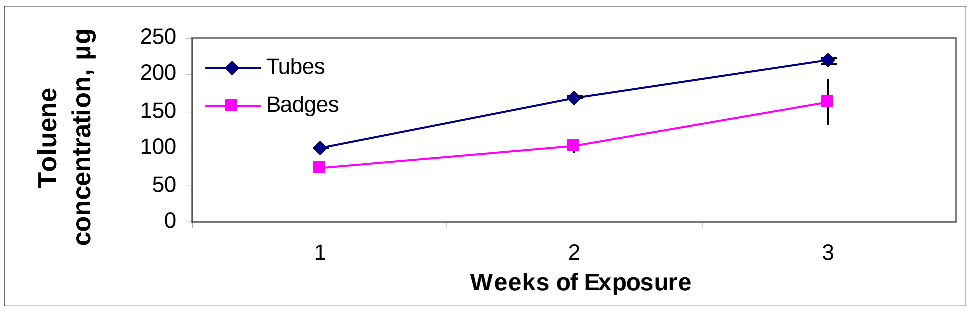

Figure 2. Toluene - 21 days (3 weeks).

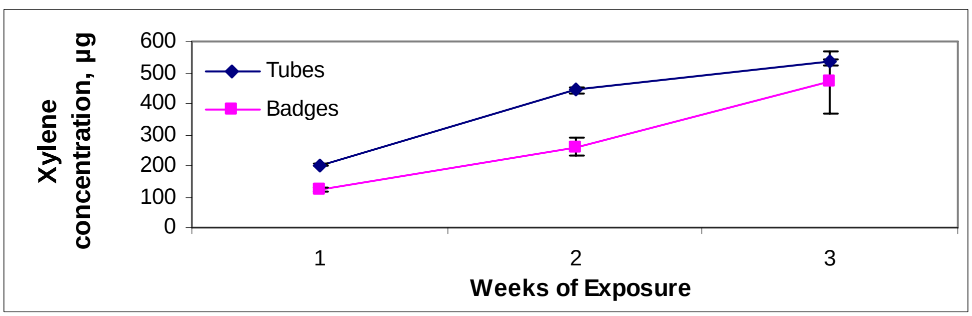

Figure 3. Xylene - 21 days (3 weeks).